

MV-3 Communication Subsystem

G. S. Parks, R. S. Markham, and T. J. Rowden
Tracking Systems and Applications Section

M. L. MacMedan
Mission Information Systems Engineering Section

The Operational Mobile VLBI Data Acquisition System (MV-3) being designed by JPL requires that a voice link be established between the mobile data system and a fixed site. A communications subsystem was incorporated in the MV-3 design which consists of HF radio, VHF mobile radio telephone and conventional land line telephone. The HF antenna design was optimized for short and long range transmission using both inverted V and yagi antennas mounted on a self-supporting telescoping mast.

I. Introduction

The Operational Mobile VLBI Data Acquisition System (MV-3) is being implemented by JPL in support of the NASA Crustal Dynamics Project. MV-3 is also known as Operational Radio Interferometry Observing Network (ORION) and consists of an electronics van and 5-meter dish antenna with transporter. Operating in conjunction with one or more VLBI data acquisition systems, it will provide a means of measuring length and orientation of vectors between sites in areas of geophysical interest. The technology used to accomplish this is Very Long Baseline Interferometry (VLBI, Ref. 1).

A communications subsystem (COM) was incorporated to establish a voice link between the mobile data system and a fixed site. This is necessary to coordinate experiment start times and help solve problems as they arise during setup or during data acquisition. Reliable communications are also necessary for safety reasons while MV-3 is operating in remote locations.

A single control station will be used to coordinate all mobile and fixed data acquisition systems during an experi-

ment. Therefore, MV-3 need only communicate with this one station which can act as a relay for messages to other stations.

II. Requirements

The MV-3 Design Requirements Document (an internal JPL document) forms the basis for COM requirements. Generally, COM must include those transceivers and antennas necessary to provide 90% reliable voice contact communications to the control station from any place in the continental United States. Practical reasons dictated the limitation to the continental U.S. in that it would be difficult to design a system around all possible foreign regulations and systems available. Foreign operation may therefore require tailoring the COM capability to meet the requirements.

Because MV-3 is a mobile system, COM must also meet the following requirements:

- (1) COM components must survive road vibrations and stress encountered while in transit.

- (2) Equipment mounted to the exterior of the electronics van must meet provisions set down by state vehicle codes. The design requirements specifically prohibit the use of equipment which would require that MV-3 obtain special road permits.
- (3) COM must meet its reliability requirement under a wide range of terrain conditions. Mountains and valleys must be considered in the design.
- (4) The setup and teardown of the COM subsystem should be held to a practical minimum. Ease of operations can considerably lower cost to operate MV-3.

III. Tradeoff Studies

The following seven modes of communication were considered for their merits in optimizing the MV-3 COM design.

- (1) Land lines.
- (2) Low and medium frequency radio.
- (3) High frequency radio.
- (4) Repeater communications.
- (5) VHF radio telephone.
- (6) Satellite microwave.
- (7) ATS satellite.

A. Land Lines

The land line system considered here is that which is commercially available from the telephone company. Once linked, it achieves better than the 90% reliability imposed on COM and is rarely affected by unpredictable environmental conditions.

The land line system has two drawbacks. First, it depends on the availability of the lines. Some remote locations would require a special hookup, raising the cost of the system. Second, it poses a logistics problem. Arrangements must be made weeks in advance for the connection. Also, a representative of the user must be available at the site to coordinate the placement of the lines. The land line system is therefore practical only in cases where other systems cannot be used, or when the length of stay at a particular site warrants its installation.

B. Low and Medium Frequency Radio

Radio communication is generally a practical alternative to land lines. Each carrier frequency subdivision has its own main characteristics, as summarized in Table 1. Low frequency (LF) radio is generally good for medium and long range transmission, either by traveling close to the ground (ground wave)

or reflecting off the ionosphere (sky wave). Medium frequency (MF) transmission is good for short range communications such as local AM broadcasting. At night, MF can sometimes bounce off the ionosphere, which increases its range. Picking up a faraway AM broadcasting station at night is a typical example of this.

One serious disadvantage of LF or MF is that the antenna is extremely large. The length of an efficient antenna is typically either $1/4$ or $1/2$ wavelength, which implies that the antenna would be tens or hundreds of meters long. This is practical only in fixed locations where such an antenna could be permanently installed.

C. High Frequencies

High frequency (HF) transmission is generally good for short distance ground wave and long distance sky wave communication. Figure 1 shows the typical range for HF, which has a wavelength from 10 to 160 meters. With multiple hops, HF will also transmit over intercontinental distances. Ground wave transmission is usually useable up to 320 km, but depends greatly on terrain, while sky wave transmission works at distances greater than 160 km.

HF has two drawbacks. First, it still requires a large antenna. Typical HF antennas are from 3 to 60 meters in length depending on the frequency. Second, proper ionospheric conditions are required for reliable transmission. HF alone would not meet the reliability requirement imposed on COM.

D. Repeater Communications

Frequencies above the HF band are generally good only for ground wave transmission and require repeaters to extend its range. Frequencies in this range include very high frequencies (VHF), ultra high frequencies (UHF), and microwave. Repeater stations are usually on mountain tops, and receive the incoming signal while retransmitting the same signal to a receiver that would otherwise be out of range of the first transmitter. The advantages of this system are: First, these frequencies are only negligibly affected by atmospheric or environmental conditions. Repeater communications are therefore very reliable as long as the user's transceiver is in range of a repeater. Second, the antennas for this mode of transmission are small, typically a few feet, which simplifies design and operations. The disadvantage of this scheme is the requirement for costly repeater systems throughout the area of anticipated use. This system would only be practical for COM if existing repeater systems are used.

E. VHF Radio Telephone

Mobile VHF radio telephones have all of the characteristics of a repeater communications system. A critical advantage is

that radio telephones use a repeater network owned and operated by the telephone company and its contractors. Through mobile telephone charges, repeater time is rented and shared by multiple users, bringing the cost down to an affordable value. This system is designed around multiple channels shared by mobile telephone users in the immediate area. Direct dial and automatic scanning features will be available this year, which will eliminate the requirement that channel number be coordinated before the call is placed.

The disadvantages of radio telephone are: First, the system is not designed to reliably cover remote areas, particularly off-highway. Also, mountains in the radio path to the repeater can reduce its reliability considerably. Second, the radio telephone channels tend to be overcrowded in populous areas. Some waiting period could be encountered before contact is made.

F. Satellite Microwaves

As the frequency spectrum has become crowded over the years, microwaves have become popular for transmitting information and messages. Microwaves are negligibly affected by atmospheric conditions, but because of their short wavelength (< 0.3 m), transmission is in a strict line of sight path and thus requires repeaters to extend the range. Satellite repeaters are practical for this purpose because of the large area of the earth covered by each satellite. Numerous microwave transceivers can beam signals to a satellite repeater for reliable short or long range transmission.

There are two considerable disadvantages of satellite microwave systems for MV-3. First, a large dish antenna (3 to 5 meters) must be pointed at the satellite for transmission. MV-3 already incorporates a dish antenna, and to add another would raise the costs significantly and decrease its mobility and versatility. Second, renting satellite time is costly.

G. ATS Satellite

NASA-Goddard Space Flight Center is currently coordinating the use of two VHF communications satellites (ATS) which are available to government experimenters on a priority basis as determined by NASA. When available, these satellites would provide reliable communication for MV-3 operations. There are, however, three serious disadvantages. First, use of the satellites must be coordinated well in advance of anticipated use. This generates manpower requirements to coordinate the logistics and also disqualifies the system for emergency use. Second, since ATS is shared by other users, there may be times when the system is unavailable to MV-3. Third, ATS is an experimental satellite with no guarantees that it will continue to function for an extended period of time.

IV. Systems Chosen

From the characteristics of each system, it was decided that COM incorporate the following communication modes: (1) land lines, (2) VHF mobile radio telephones, (3) HF radio. Normally the VHF mobile radio telephone will be used where available because of its ease of use. The HF radio will back up the radio telephone as necessary. If a long stay at a site is anticipated, MV-3 will be configured with standard telephones so that a direct land line connection is possible.

Both the mobile radio and land line telephones are standard telephone company installations. A 1-m whip antenna will be installed on the van roof with a cable leading to the VHF transceiver mounted in an equipment rack. MV-3 is equipped with a 12-Vdc battery system which will power the mobile telephone. This system will therefore be useable before the MV-3 generators are started.

The HF radio requires multiple frequencies on which it will operate to ensure reliable transmission over a wide range of distances (Fig. 2). The lowest frequency (channel) is determined for its ability to transmit over short distances. Higher frequency channels should progress in octaves to a channel with long range transmission characteristics. COM will use the frequencies issued to NASA (namely 3.395, 6.9825 and 14.455 MHz) which have the necessary qualifications.

V. HF Antenna Tradeoffs

A well designed antenna is critical for reliable HF communication. Because of its size, it also warrants the most attention to optimize ease of operations. The following antenna types were considered for tradeoffs for the HF system (Fig. 3): (1) whip, (2) horizontal dipole, (3) inverted V dipole, (4) yagi.

A. Whip

The whip antenna has two advantages. First, as can be seen from its radiation pattern (Fig. 4), the whip transmits best on horizontal paths. This quality is excellent for transmitting ground wave and long range (> 750 km) sky wave. In both cases the radiation angle (angle between the main transmission lobe and horizon) is small. Second, the whip transmits in all horizontal directions (omnidirectional), eliminating a need for antenna pointing.

The whip has two disadvantages. First, it does not transmit well at high angles required for short distance sky wave transmission (150-750 km). This mode is usually necessary in mountainous areas when ground wave communication is not possible. Second, the whip requires a resonant ground plane for optimum performance which would be difficult to set up.

The electronics van roof might be used as a substitute but would not provide optimum performance.

B. Horizontal Dipole

The horizontal dipole transmits well both horizontally and vertically at all but very low radiation angles. Normally one thinks of the horizontal dipole as having a figure-eight shaped radiation pattern, which is only true in free space. A computer-generated mathematical model (Ref. 2) simulated the radiation patterns as a function of antenna height. These are shown in Fig. 5 and were confirmed by antenna range tests. This antenna is generally good for short and medium range (0-1800 km) transmission using both ground and sky waves. Another advantage of the dipole is that no ground plane is required for good performance.

A disadvantage of the horizontal dipole is that it requires two long support towers, which would be difficult to erect. In order to achieve the desired radiation angle, both towers must be more than 10 km high. (This antenna height also helps match the antenna impedance to the 50 ohm transceiver as shown in Fig. 6). Further difficulties arise in positioning the towers for cases in which the electronics van is parked near a hill.

C. Inverted V Dipole

The inverted V dipole is different from the standard dipole only in that the antenna ends are brought down close to the ground. A similar computer-generated antenna pattern (Fig. 7) shows that the inverted V, like the horizontal dipole, transmits well horizontally and vertically. Like the horizontal dipole, the inverted V does not require a ground plane and will transmit reliably up to distances of about 1800 km.

An important advantage of the inverted V over the horizontal dipole is that it requires only one high support tower. This tower can be mounted on the electronics van with the dipole ends brought down to near ground level. Because the inverted V is nearly omnidirectional, any convenient orientation can be used. The antenna ends can be held in place by tripods or sandbags, depending on terrain. Also, because of the antenna shape, the inverted V requires less space than the horizontal dipole.

D. Yagi

The yagi antenna is a very directional antenna which focuses almost all of the radiation energy in one direction (Fig. 8). Because of the large gain in signal strength in the one direction, the yagi will exceed the performance of other antennas when aligned properly with the point of contact. Unfortunately, the yagi is very large for HF frequencies.

Fixed-installation yagi antennas are rarely constructed for frequencies less than 6 MHz. Because of the mobility requirements of MV-3, the yagi will only be practical with the 14.455-MHz channel. Even at this frequency the boom length is about 25 feet, which is almost the limit of what the MV-3 crew could easily erect. Fortunately, the 14.455-MHz channel will usually only be used for long distance communication when the extra antenna gain is needed. Therefore the yagi is only practical in this case for long range transmission (> 1800 km).

VI. Antenna Selection and Implementation

Using the previous information it was decided that COM incorporate both the inverted V dipole and the yagi antennas. For most applications of short to medium range contact (0-1800 km), the omnidirectional inverted V will be used. The yagi, which will be more difficult to erect, will be used only for long range contact (> 1800 km), using the 14.455 MHz channel. If conditions require that other channels be used for long range contact, the inverted V will be available.

Tuned resonant traps in the inverted V will eliminate the need for separate antennas for each channel. These traps are resonant L-C circuits which essentially "divorce" the wires beyond the traps at the appropriate frequency. The traps are positioned in the antenna so that each operating frequency will be matched properly to the antenna. The overall length of the antenna is 43.2 m, which is approximately $1/2$ wavelength at 3.395 MHz.

Both the inverted V and the yagi antennas are supported by a pneumatic telescoping mast as shown in Fig. 9. The mast is available as a catalog component from Wil-Bert Company and is self supporting and easy to erect. Mobile television systems are the prime user of the mast for transmitting microwave video information locally. The mast is to be mounted to the van rear door with a separate air compressor mounted near the van suspension. Activating the compressor extends the mast from 2.2 to 14.8 meters. The entire mast is rotatable by hand for yagi antenna alignment.

As can be seen by Fig. 8, the yagi favors a high mounting position for long distance communication. As the height of the yagi is increased, the radiation angle decreases, which is desirable to help overcome the barrier of the earth's curvature. The 14.8 m mast plus 1.2 m of trailer suspension holds the yagi approximately $3/4$ of a wavelength above ground.

The inverted V antenna is supported on the ends by two tripods to reduce the capacitive effect of the ground near the antenna ends. If the terrain makes this impractical, the antenna ends can be supported by rope tied to sandbags.

References

1. Brunn, D. L., McLaughlin, F. D., Sweetser, B. M., Thom, E. H., and Wu, S. C., "ORION Mobile Unit Design," in *TDA Progress Report 42-60*, Jet Propulsion Laboratory, Pasadena, Calif., December 1980.
2. Covington D. W. "Radiation Patterns of V Dipoles over Perfect Ground," *QST*, April 1970.

Bibliography

- Bennington, T. W., *Short-Wave Radio and Ionosphere*, W. & J. MacKay & Co., Ltd., Chatham, Great Britain, 1950.
- Sinnema, W. *Electronic Transmission Technology*, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1979.
- The A.R.R.L. Antenna Book*, American Radio Relay League, Inc. Newington, CN.

Table 1. Main transmission characteristics of frequency classes

Classes	Frequency subdivisions	Main characteristics	Principal uses
Very long waves and long waves	VLF and LF	Wave travels to considerable distances over earth's surface and to great distances by reflection from lower edge of ionosphere	Medium and long distance point-to-point communication. Long-wave medium distance broadcasting
Medium waves	MF	Wave travels over earth's surface to relatively short distances during day; at night some energy comes from ionosphere and range increases	Local broadcasting, marine and aircraft communication, direction finding
Short waves	HF	Wave travels up to ionosphere whence it is reflected back to earth. Conditions vary greatly with time of day and season, but great ranges obtained if conditions favorable	Long distance broadcasting, point-to-point communication. Amateur communication, etc.
Very short, ultra short, and microwaves	VHF, UHF, microwaves	No ionospheric reflection. Wave travels directly through lower atmosphere from transmitter to receiver	Short distance communication, FM broadcasting, television, radar, aircraft guidance systems. Amateur communication

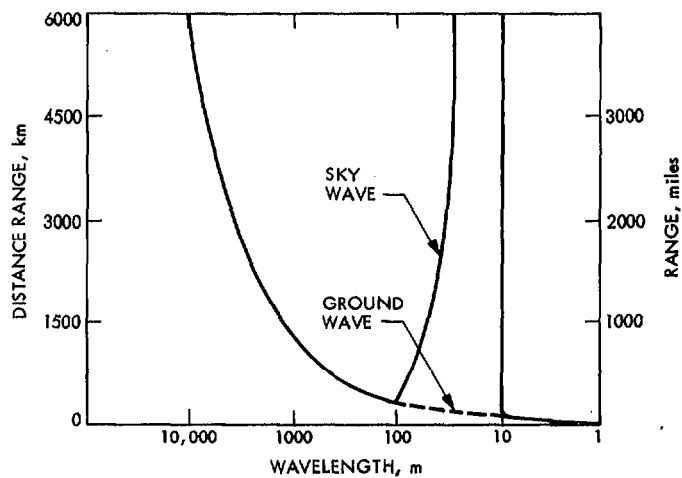


Fig. 1. Variation in range with wavelength

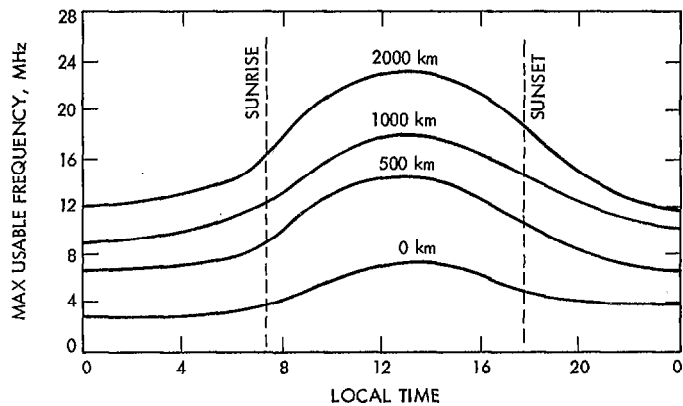


Fig. 2. Maximum useable frequency chart

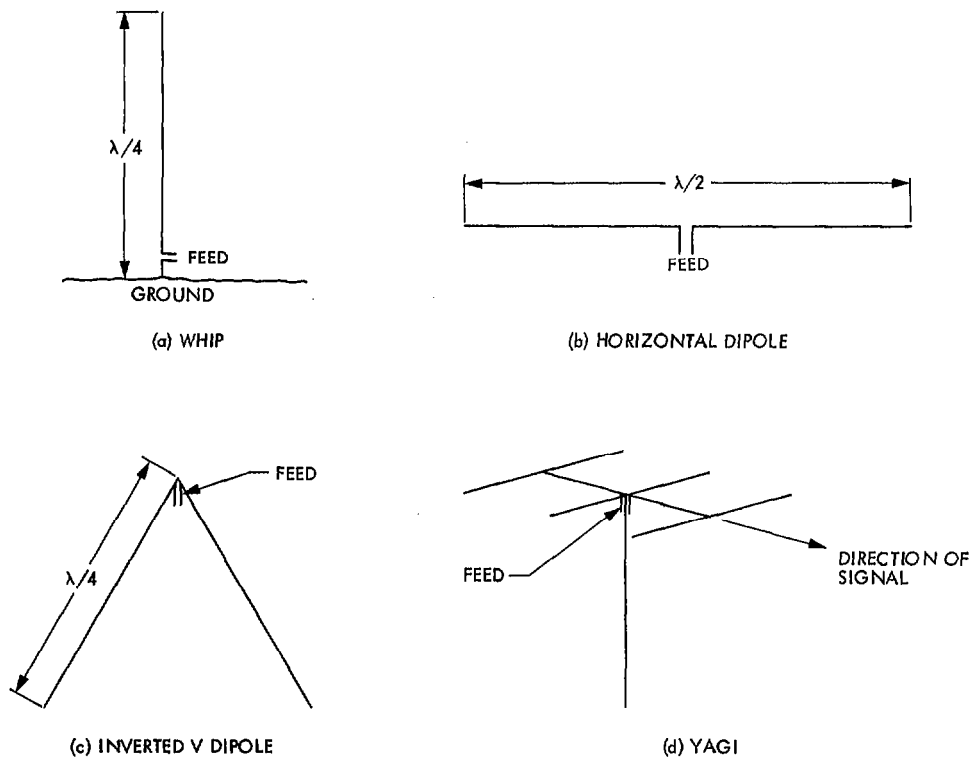


Fig. 3. Antenna configurations

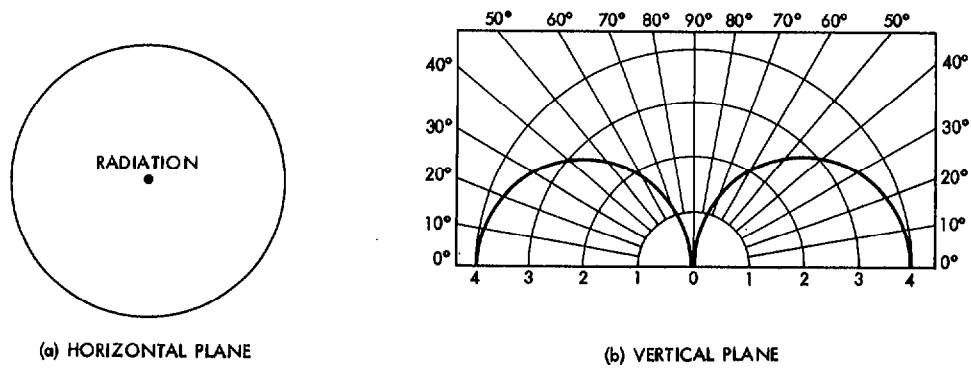


Fig. 4. Whip radiation patterns (assuming ideal ground plane)

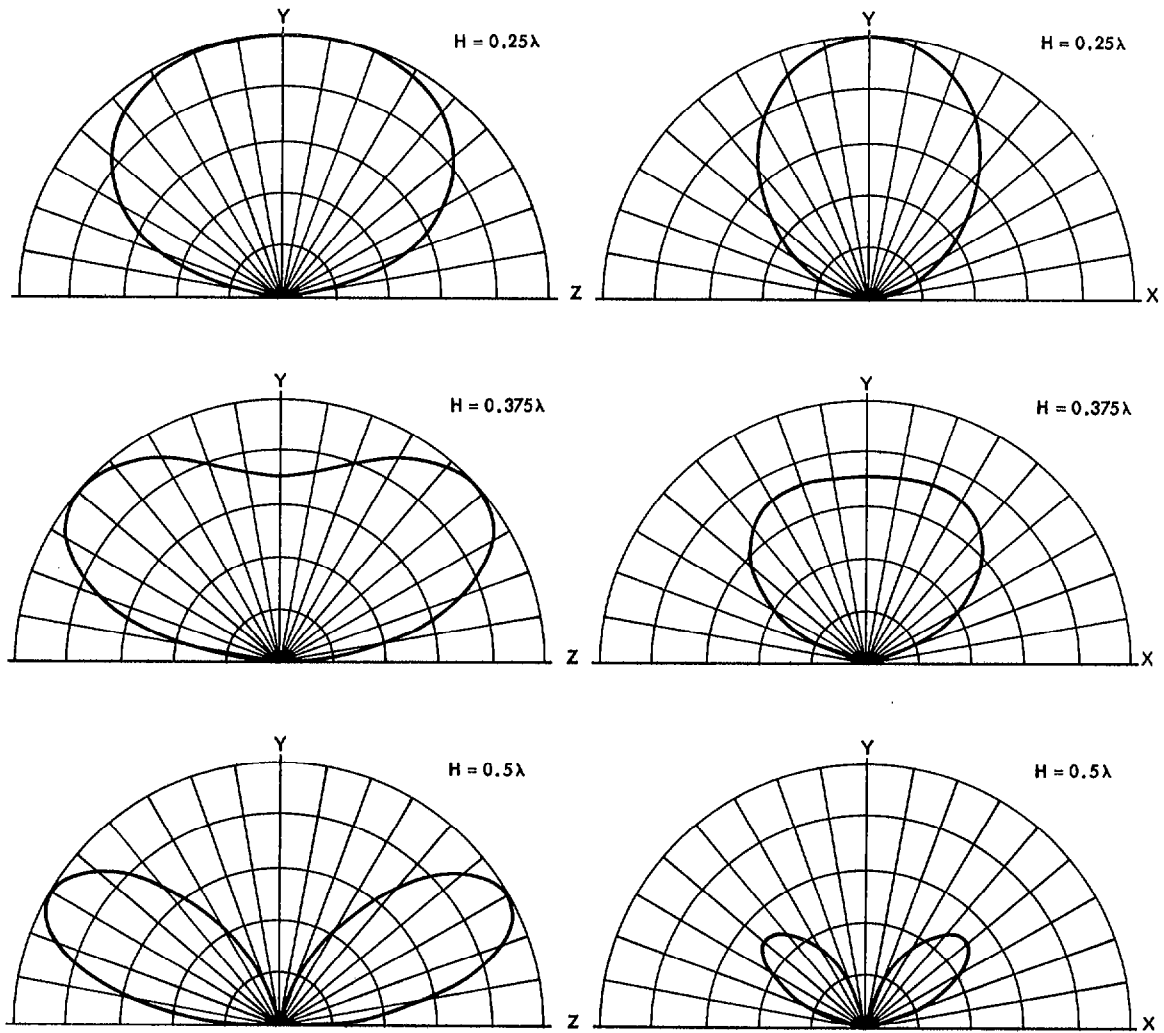


Fig. 5. Antenna patterns off the end of (left) and broadside to (right) a horizontal dipole as a function of antenna height above ground (in wavelengths λ)

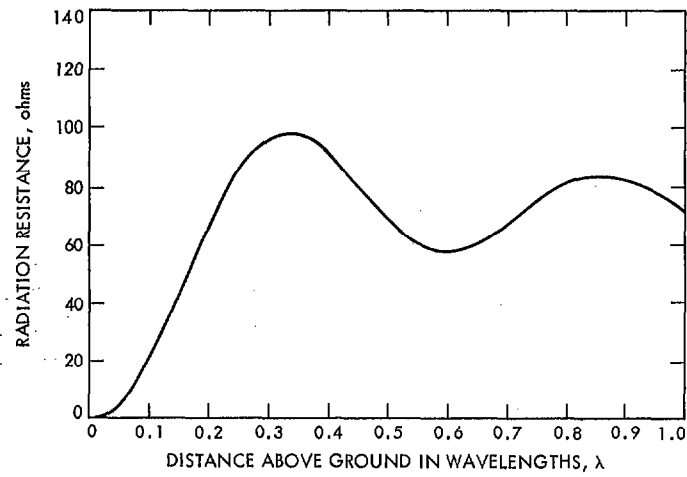


Fig. 6. Input resistance of a horizontal half-wavelength dipole antenna at a height λ wavelengths above a ground plane

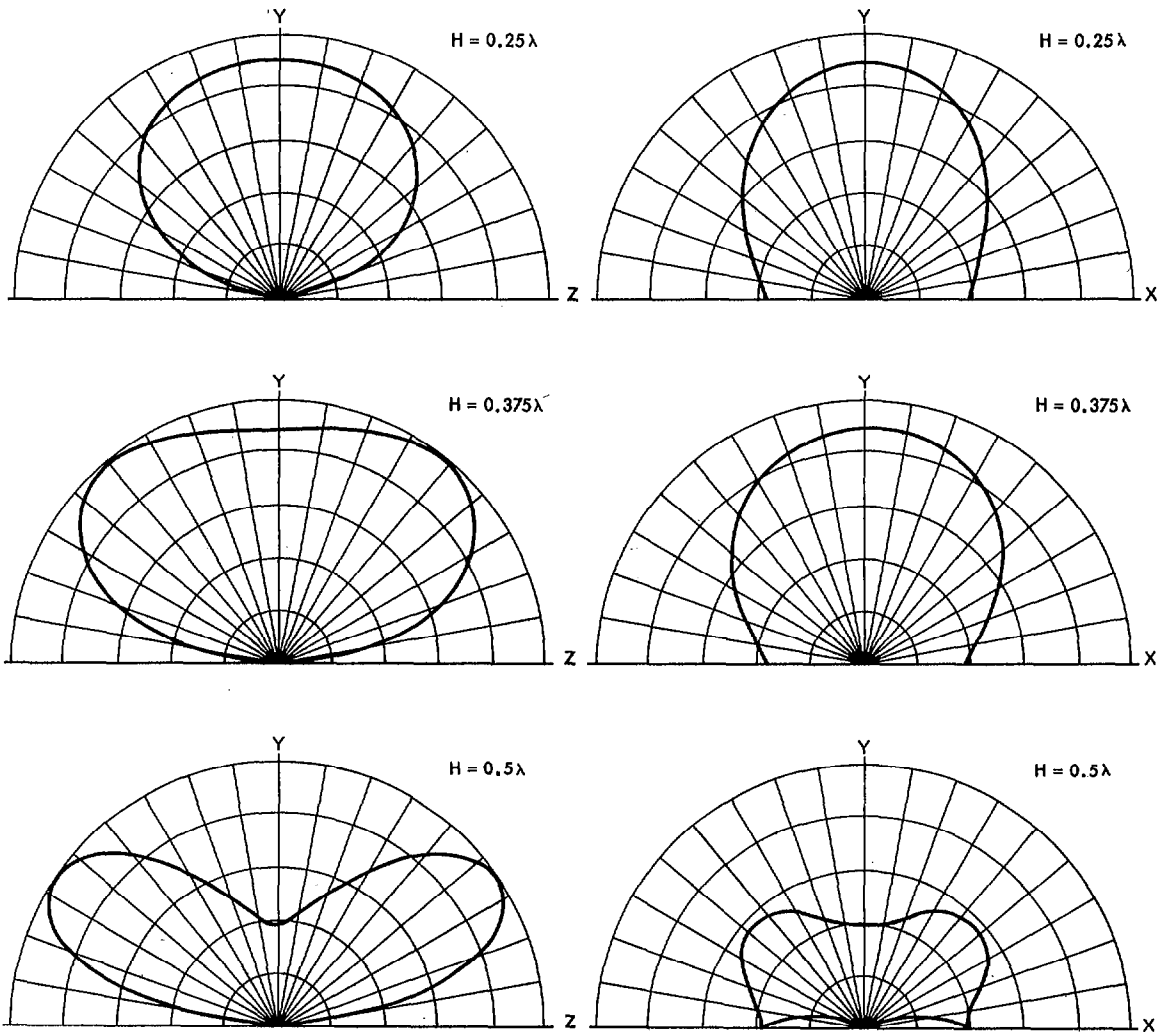


Fig. 7. Antenna patterns off the end of (left) and broadside to (right) an inverted V dipole as a function of antenna height above ground (in wavelengths λ)

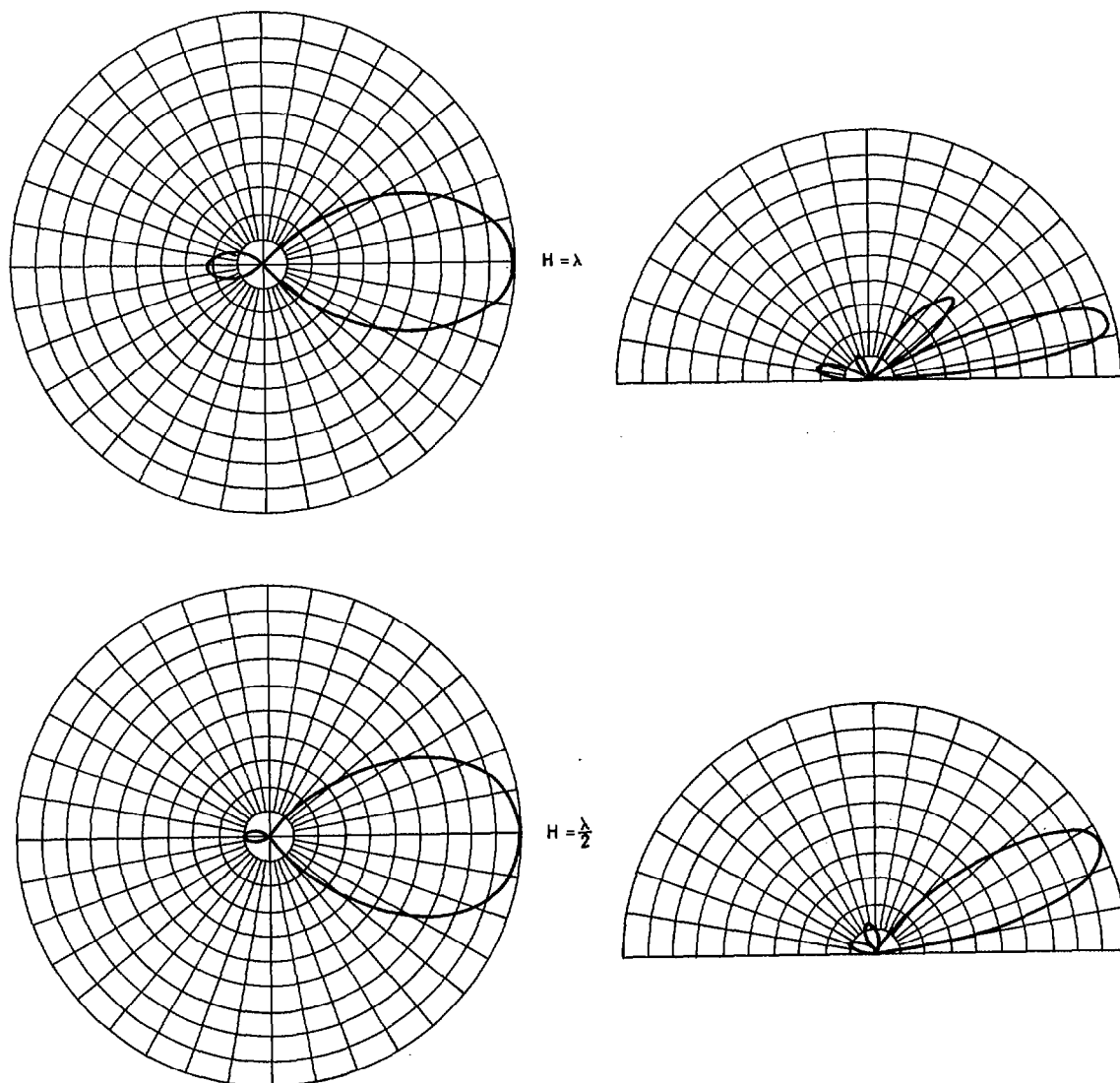


Fig. 8. Yagi radiation patterns for horizontal plane (left) and vertical plane (right) as a function of antenna height (in wavelengths λ)

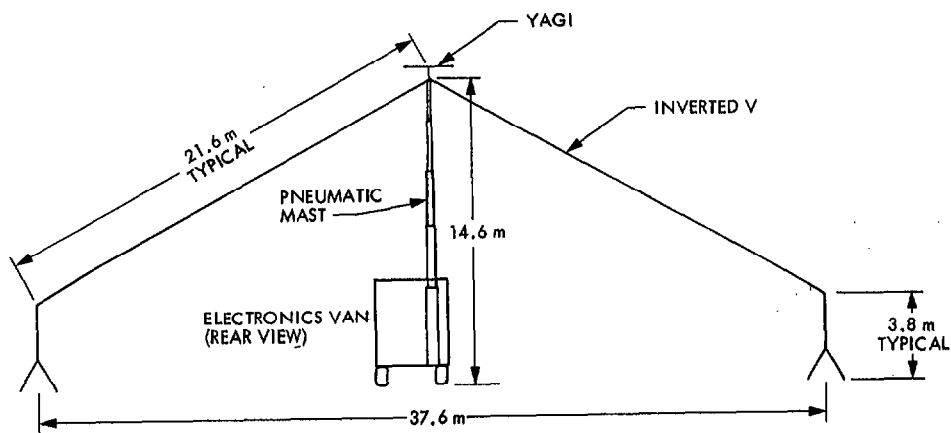


Fig. 9. Antenna Implementation